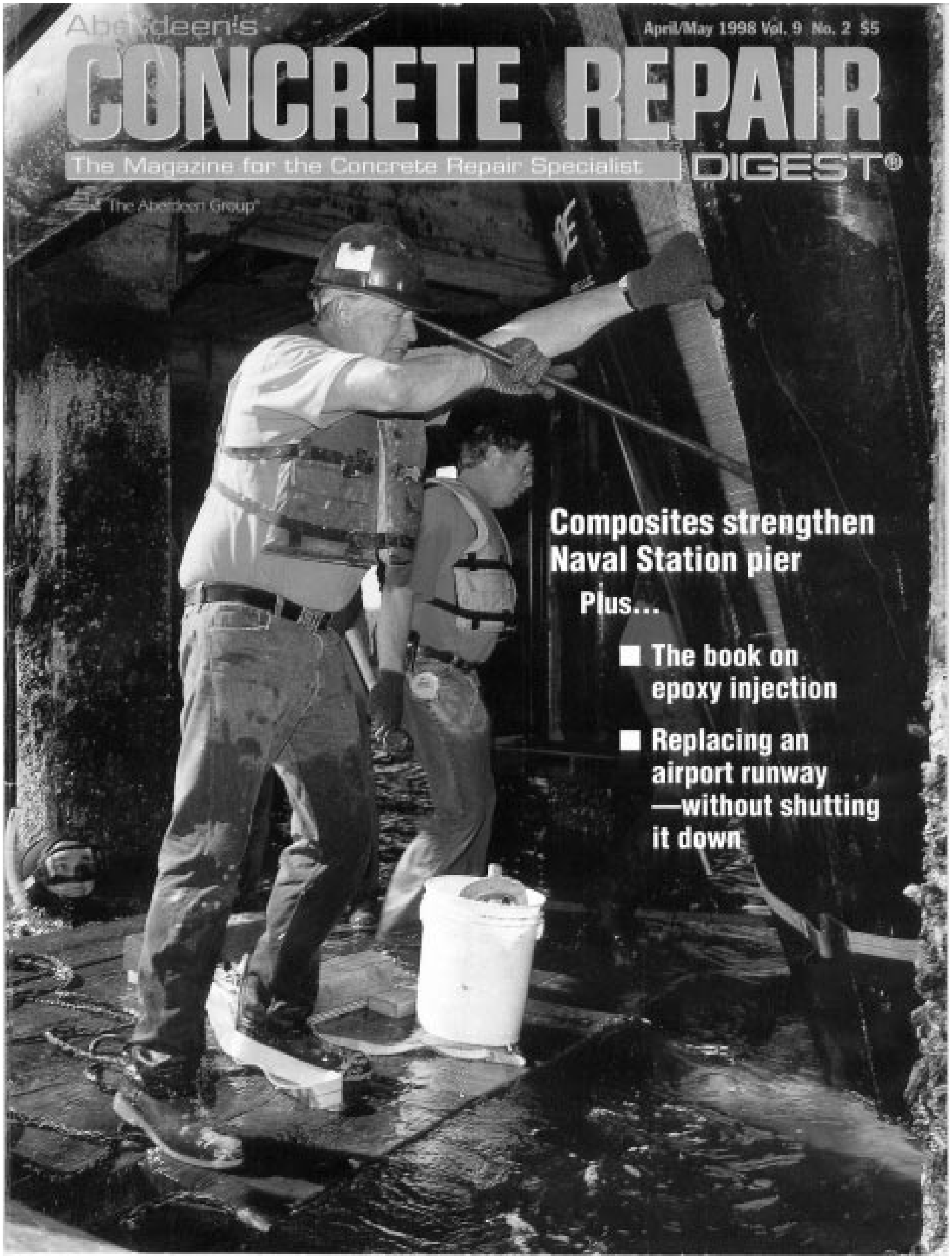
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CONCRETE REPAIR
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Composites strengthen Naval Station pier
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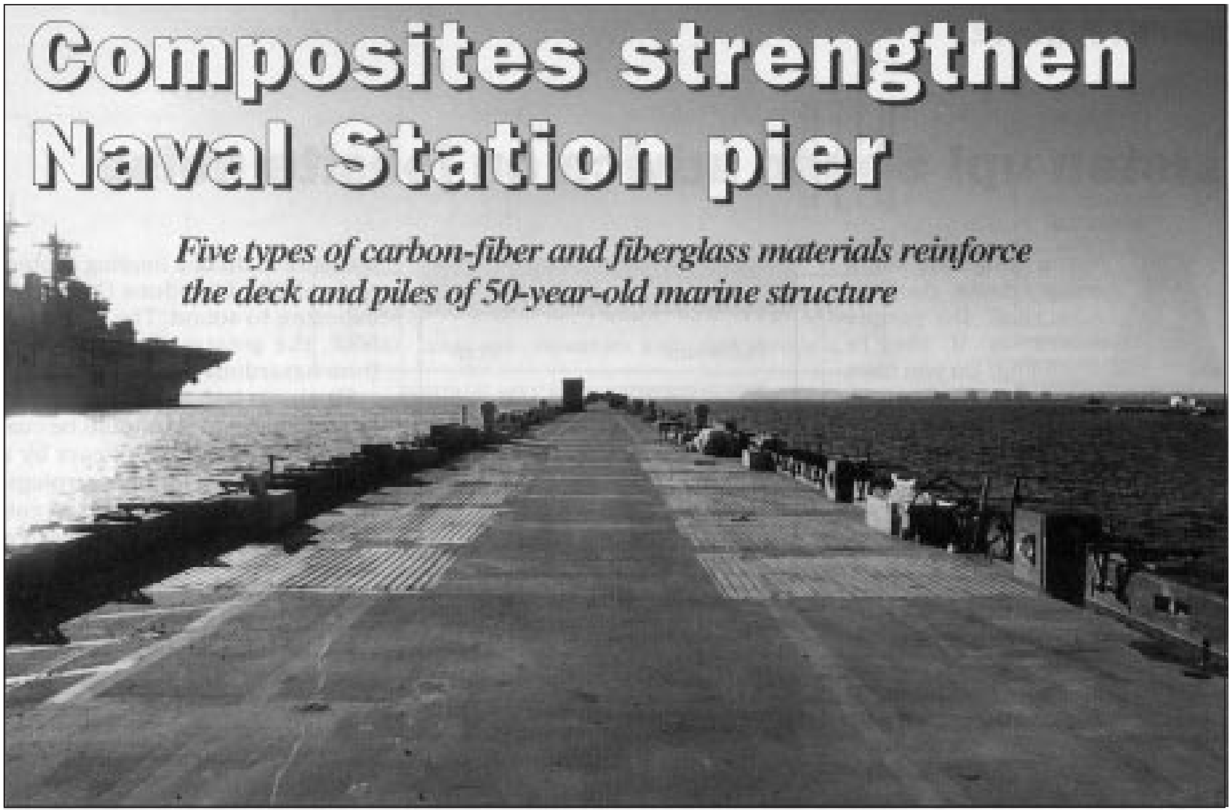
Replacing an airport runway —without shutting it down

Composites strengthen Naval Station pier

Five types of carbon-fiber and fiberglass materials reinforce the deck and piles of 50-year-old marine structure



All photos by William P. Young Construction Inc.

The 1,500-foot-long pier lacks the flexural reinforcement needed to support 50-ton mounted cranes

By Martin S. McGovern

To upgrade a pier at Naval Station, San Diego, the U.S. Navy is taking a bold step into the world of high-tech strengthening materials.

As part of a project that began last November, the Navy is retrofitting Pier 12 with three types of carbon-fiber reinforcement and two types of fiberglass reinforcement. This is the Navy's largest use of composite materials to strengthen a concrete structure.

Why composites?

A major reason is that composite strengthening, when compared to conventional methods, greatly reduces the downtime of the pier. The light composites can be placed by hand, eliminating the need for bulky material-handling equipment that would otherwise prevent ships from docking during the project. And because composite strengthening usually doesn't require additional concrete, you don't have to wait several days for the concrete to cure. The composites are bonded to the concrete with epoxies, which reach design strengths in a matter of hours.

For the Navy, reduced downtime is a major benefit. Consolidation of the Navy over the past several years has left fewer piers at which to park the same number of ships. "When we do a conventional upgrade, we have to shut down the piers for up to a year, says George Warren, technical leader for the Naval Facilities Engineering Service Center (NFESC), Port Hueneme, Calif. "In this day of an overcrowded waterfront, that's not acceptable."

The light weight of composites offers the Navy another benefit, especially in California's seismic zones. For example, a common strengthening method has been to increase the thickness of the deck. But during an earthquake, the swaying of this additional weight causes excessive stresses to develop in supporting members. "As civil engineers, we usually say 'Weight be damned, we're going to build something massive,"' says Warren. "But seismic factors require us to increase the stiffness of the structure without adding weight."

Perhaps the most important long-term benefit of composites is that, unlike steel, they do not corrode. This is especially important in marine environments where saltwater can make quick work of external steel reinforcement.

The Pier 12 experiment

Pier 12 was constructed in 1946 to berth the Navy's mothball fleet stationed in San Diego after World War II. The pier's 30-foot-wide deck consists of a 24-inch-thick central section flanked by 8-inch-thick slab sections on either side (Figure 1). Three vertical bearing piles and two batter piles support the pile caps. Originally designed to carry only rail-mounted cranes, the 1,500-foot-long pier must now support heavier truck-mounted cranes to service today's larger ships.

The pier lacks the required flexural reinforcement for this change in service conditions. The current ACI code and the U.S. Department of Defense's MILHDBK 1025/1 require a minimum flexural steel ratio of 0.005 for the pier's Grade 40 reinforcement. However, when the piers were constructed, steel ratios as low as 0.001 were allowed. The NFESC conducted a load test and evaluation of the pier in January 1995 and concluded that the 8-inch-thick deck could not support portable cranes because it lacked flexural reinforcement. "I estimate that about one-third of our piers face similar problems and, of these, about one-half can be upgraded by adding external reinforcement," says Warren.

Currently, 30-ton truck-mounted cranes can be positioned only over the pile caps in the middle of the deck. The large ships berthed on Pier 12 require a longer reach and greater payload than is provided by 30-ton cranes. Therefore, engineers from the NFESC designed a strength upgrade of Pier 12 to accommodate 50-ton cranes.

This experimental project involves strengthening 12 of the pier's 14-foot-long spans and strengthening the dowel-pinning areas of 20 piles for increased seismic resistance. The negative moment capacity of the deck is increased by embedding pultruded carbon-fiber rods into the top of the deck over the pile caps. The positive moment capacity of the deck is increased by installing fiberglass I-beams, pultruded carbon-fiber strips, and laminated carbon-fiber/epoxy fabric to the underside of the deck between the pile caps.

The project's general contractor is William P. Young Construction Inc., Foster City, Calif. Here is a summary of the construction methods for the composite reinforcement:

Pultruded carbon-fiber rods

To increase the negative moment capacity of the deck over the pile caps, workers embedded X-inch-diameter pultruded carbon-fiber rods into slots saw-cut into the deck (Figure 2). Containing 65% carbon fiber and 35% epoxy, the carbon fiber rods have a tensile strength of 240 ksi—six times that of the existing reinforcing steel. The 10-foot-long rods were placed into 5/8-inch-wide, 7/8-inch-deep longitudinal grooves saw-cut into the deck on 4-inch centers.

After sandblasting the slots, workers bonded the rods in place with an epoxy extended 20% with #60 mesh silica sand. To prevent UV degradation of the epoxy, the top >(inch of the grooves was filled with an epoxy mortar containing three parts sand to one part epoxy.

Before and after cutting the

(more)

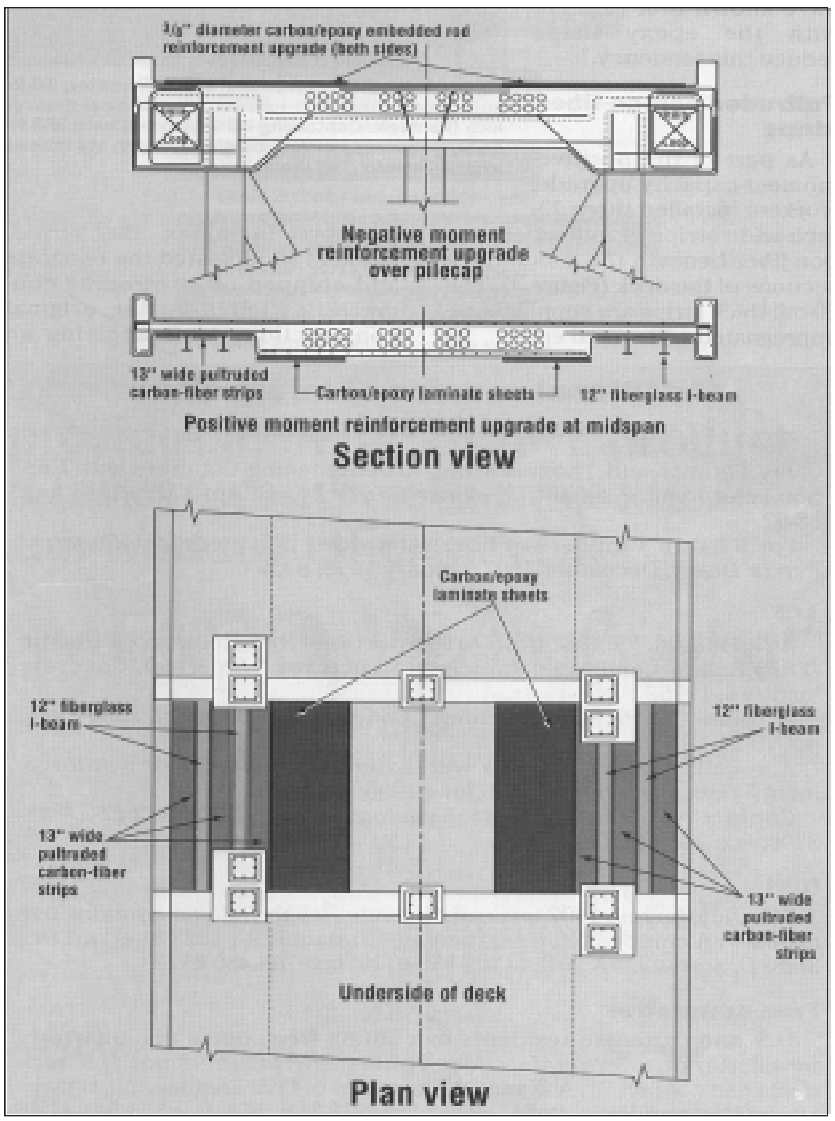


Figure 1. Plan and section views of composite reinforcement strengthening. The negative moment capacity of the deck is increased by embedding pultruded carbon-fiber rods into the top of the deck over th epile caps. The positve moment capacity of the deck is increased by installing fiberglass I-beams, pultruded carbon-fiber strips and laminated carbon-fiber / epoxy fabric to the underside of the deck between the pile caps.

slots, workers applied a penetrating epoxy to the deck. This provided two benefits: It helped prevent minor edge spalls from developing during sawing and helped prevent transverse cracking between the saw cuts. "We knew that cutting slots would invite crack growth," said Warren. "Our lab tests have shown that priming with the epoxy helps reduce this tendency."

Figure 2. Workers embedded 3/8-inch-diameter, 10-foot-long pultruded carbon-fiber rods into logitudinal grooves saw cut into the deck. Containing 65% carbon fiber and 35% epoxy, the carbon fiber rods have a tensile strength six times that of the existing reinforcing steel.

Pultruded carbon-fiber strips

As part of the positive-moment-capacity upgrade, workers installed three 13-inch-wide strips of pultruded carbon fiber beneath the 8-inch-thick sections of the deck (Figure 3). The SO-mu-thick strips are supplied pre-impregnated with cured epoxy.

Before installing the strips, workers sandblasted the concrete and chipped off protruding concrete fins left from the original construction. After applying an epoxy primer, workers troweled an epoxy paste onto the surface to fill surface defects and provide a smooth bonding surface. After cutting the pultruded strips to the appropriate length, workers bonded the strips to the deck with epoxy.

With a tensile strength of 460 ksi, the carbon-fiber strips are eight times stronger than conventional Grade 60 steel. Therefore, to achieve the same strength using steel, 0.4-inch-thick plate would have been required. Not only is such a plate difficult to lift, it must be mechanically anchored to the deck.

Pultruded fiberglass I-beams

To increase the shear strength and positive moment capacity of the deck, workers installed two 12-inch-deep fiberglass I-beams between the three puitruded carbon-fiber strips. The I-beams were bonded with epoxy to the underside of the deck and the ends of the beams were bolted to the pile caps (Figure 4). "Because the fiberglass I-beams weigh only 30% that of steel, two workers could easily lift and position the 12-foot-long beams without using jacks or other heavy lifting equipment,"

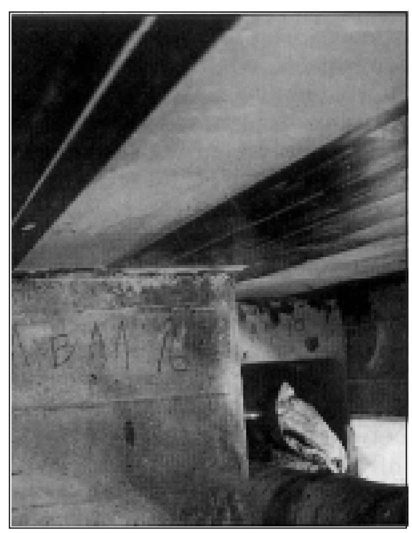


Figure 3. Three 13-inch-wide strips of pultruded carbon fiber were bonded with epoxy beneath the 8-inch-thick sections of the deck.

Additional sources of Information on composite strengthening

Jay Thomas and Thomas Kline, "Strengthening Concrete with Carbon-Fiber Reinforcement," *Concrete Repair Digest,* April/May 1996, pp. 88-92.

For a list of suppliers of fiber-reinforced polymers, see *Concrete Repair Digest,* December 1997/January 1998, p. 304.

ACI

ACI 440R-96, "State-of-the-Art Report on Fiber Reinforced Plastic (FRP) Reinforcement for Concrete Structures," American Concrete Institute, 1996.

A. Nanni, "CFRP Strengthening," *Concrete International*, June 1997, pp. 19-23.

A. Nanni, "Concrete Repair with Externally Bonded FRP Reinforcement," *Concrete International*, June 1995, pp. 22-26.

Contact ACI, P.O. Box 9094, Farmington Hills, Ml 48333 (248-848-3700; fax: 248.848.3701)

ICRI

The July/August 1997 issue of *Concrete Repair Bulletin* contains five articles on composite strengthening. Contact ICRI, 1323 Shepard Dr., Suite D, Sterling, VA 20164 (703-450-0116; fax: 703.450.0119)

Free newsletter

U.S. and Canadian residents can obtain free copies of a quarterly newsletter on fiber-reinforced polymers, *FRP International.* U.S. residents can contact Dr. A. Nanni, Department of Civil Engineering, University of Missouri-Rolla, Rolla, MO 65409 (S73-3414553; fax: 573.341.4729; e-mail: nanni@umr.edu). Canadian residents can contact Dr. SM. Rizkalla, University of Manitoba, Winnipeg, Manitoba, Canada R3T 5V6 (204-474-8506; fax: 204.474.7519; e-mail: rizkall@ccumanltoba.ca).

said Richard Bohner, composite design engineer and project manager for William P. Young.

The 30-ksi tensile strength of the fiberglass beams is only half that of Grade 60 steel. But the low weight-to-thickness ratio of the fiberglass provides a structural benefit. "Although an equivalent-strength steel beam would be about half the size, it would provide less stiffness, and buckling of the shear web would be a potential problem," said Bohner.

Figure 4. Workers installed two 12-inch-deep fiberglass I-beams between the three pultruded carbon-fiber strips. the I-beams were bonded with epoxy to the underside of the deck and the ends of trhe beams were bolted to the pile caps.

Laminated carbon-fiber/epoxy fabric

Beneath the 24-inch-thick section of the deck, workers installed 4A-foot-wide carbon-fiber fabric sheets between the pile caps. The dry fabric was saturated with a precise amount of epoxy by passing it through an onsite impregna tor. The saturated fabric was then taken down to the application site on rolls which are used to place the material. Four layers of the 50-mu-thick fabric were placed with a tack coat of epoxy applied between layers (Figure 5).

The carbon-fiber fabric has a tensile strength of 100 ksi. The four layers of fabric provided a strength increase similar to that provided by the pultruded strips.

Fiberglass pile-confinement jackets

To increase the shear strength of the piles in the dowel-pinning area, workers installed 7-foot-long fiberglass jackets around 11 batter piles and nine vertical piles. Engineers chose to wrap the 18-inch square piles with 31-inch-diameter, two-piece cylindrical jackets to allow room for portland cement grout to fill the annular space between the jacket and pile. The jacket halves are bonded with a methyl methacrylate adhesive placed within H-connectors which allow for a double lap joint (Figure 6).

Figure 6. The two pieces of the pile-confinement jackets are bonded with a methyl methacrylate adhesive placed within H-connedctors which allow for a double lap joint.

Quality control and cost

Engineers required the tensile bond of the external reinforcement to reach at least 300 psi. The installers were responsible for conducting the adhesion tests in accordance with ASTM D 4541. As construction proceeds, engineers are installing strain sensors on the external reinforcement to determine if the specified stiffness has been achieved.

Although cost figures from the Navy were not yet available, the high price of the composite materials will make the project significantly more expensive than conventional upgrades. But the benefit of reduced downtime may substantially offset the higher cost.

At press time, the project was scheduled for completion in mid-March. Warren is hoping to get 10 maintenance-free years from the composite strengthening project while monitoring the long-term performance. "The composites have a tough act to follow," says Warren. "Our original composite, steel-reinforced concrete, has served the Navy well for many years."

Credits

Engineer: Naval Facilities Engineering Service Center, Port Hueneme, Calif.

General contractor: William P. Young Construction Inc., Foster City, CAlif.

Subcontractors: Fyfe Co., San Diego; Owen Pacific Roofing & Waterproofing, San Diego

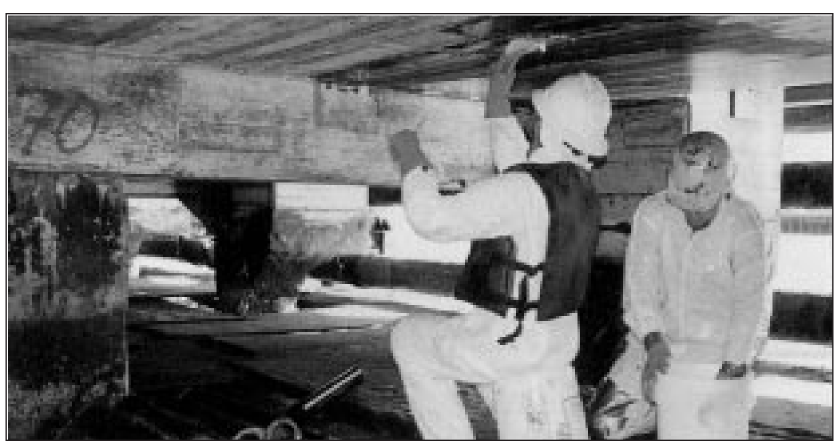


Figure 5. Beneath the 24-inch-thick section of the deck, workers installed 4 1/2-foot-wide carbion-fiber frabic sheets between the pile cap.